Sustainable Temporary Building Design in the Context of Urban Micro-Renewal: A Study on Spatial Function Optimization and Practice Based on Human Well-being

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ABSTRACT Against the background of urban development shifting from incremental expansion to stock optimization, micro-renewal has become an important path for improving urban quality by reactivating underused industrial spaces, public service nodes, and fragmented urban sites. This transformation emphasizes the reuse of existing spatial resources, the improvement of environmental performance, and the enhancement of community well-being. Temporary buildings, as flexible spatial elements, play an increasingly important role in the process of urban micro-renewal. Taking human well-being as the fundamental orientation, this study examines sustainable utilization methods and practical strategies for temporary buildings. By constructing a three-dimensional analytical framework of “environment-function-society” and combining field research, spatial simulation, post-occupancy evaluation, and case analysis, the potential of temporary buildings in optimizing spatial functions, improving environmental performance, and creating social value is systematically explored. The results show that modular design, adaptive spatial layout, and bioclimatic regulation strategies can improve the flexibility, comfort, and sustainability of temporary buildings in urban renewal scenarios. In addition, the study considers lightweight enclosure materials, intelligent sensing facilities, electromagnetic shielding requirements, and wireless communication adaptability in temporary building environments, providing support for safer and more responsive public spaces. The design methods and practical examples presented in this paper provide a theoretical basis and practical reference for sustainable temporary building innovation, especially in relation to structural flexibility, environmental adaptability, electromagnetic compatibility, and human-centered urban infrastructure.

INDEX TERMS urban micro-renewal, temporary buildings, sustainable design, electromagnetic compatibility, intelligent sensing

I. INTRODUCTION

WITH the deepening of urbanization, many cities face land shortages and the underutilization of existing space, especially in aging industrial districts where vacant production facilities lead to a lack of community functions. Addressing these issues requires repurposing the spatial footprint of historic fiber-processing zones to revitalize the urban fabric through multifunctional integration and modern spatial optimization. Against this background, urban micro-renewal, as a model of gradual and small-scale renewal, is gradually becoming an important way to improve the quality of cities. Due to the short construction cycle, high flexibility and low ecological impact of temporary buildings, temporary buildings have some unique advantages in the case of micro-renewal. However, traditional temporal buildings are usually plagued with poor space comfort, functionality and unnecessarily poor sustainability, which makes it hard to fulfill the space quality demands of modern life in cities.

Human well-being, being one of the primary goals of architectural design, has still not been given enough importance in the design of temporary buildings. Well-being includes not only the comfort of the basic physiological needs but also the higher level needs of psychological satisfaction and social interaction. Therefore, how to improve the temporary buildings human well-being value of the spatial function optimization has become the pressing issue. This study investigates temporary building design methods by integrating sustainable concepts and human well-being with high-performance lightweight enclosure materials, offering innovative spatial solutions for urban micro-renewal. By leveraging the structural flexibility of advanced fiber composites, the research provides a practical framework for creating lightweight, adaptable environments that enhance the functional quality of the modern urban fabric.

II. RELATED WORK

Research on architecture and urban planning continues to deepen. Song et al. [1] used life cycle assessment method to quantitatively analyze the impact of different wall design schemes on the energy consumption of buildings throughout their entire life cycle. Ferreira et al. [2] believe that even in virtual environments, the architecture and urban planning of natural components (such as greening, natural lighting, and water resources) can have a positive impact on users' mental health, including: reducing stress, enhancing mood and improving cognitive function. Daneshyar [3] addressed the technical requirements and design challenges of residential rooftop agriculture, such as structure, load, waterproofing, irrigation and accessibility. Yao [4] believes that niche theory provides an effective interdisciplinary perspective for understanding and coordinating the design of urban buildings and urban and rural planning. In the Islamic architectural tradition, urban design and architectural design are an organic whole. Alzahrani and Gaber [5] extracted the main principles and methods for integrating urban-scale design and architectural-scale design.

Jóźwik [6] explored the specific implications of social, technological and environmental changes for residential design in terms of spatial layout, flexibility, sustainability and community. Dervishaj and Gudmundsson[7] encourage maximizing passive solar energy utilization through design, which is of great significance for improving building energy efficiency, visual comfort and occupant well-being. Sun[8] proposed strategies such as building a flexible and resilient spatial system, strengthening architectural feature design, and optimizing the interaction of the built environment. Ke et al.[9] developed an urban and architectural design framework that integrates flood resilience. Contemporary architecture and urban planning increasingly rely on multi-source data for decision-making. Tyc et al.[10] investigated the existing applications of voxel models in the field of architecture and urban planning. Although existing research has made significant progress in multiple dimensions, it focuses on conventional permanent buildings or macro-urban planning. This paper explores innovative paths for temporary buildings as a resilient medium in urban stock renewal.

III. METHODS

A. GENERATION OF RESEARCH FRAMEWORK AND DESIGN STRATEGY

This study follows the path of "problem-oriented - strategy generation - practical verification" research, and builds an analytical framework with three dimensions: the environment sustainability, functional integration, and social inclusion. First of all, through the systematic study of spatial characteristics and the use requirements of urban micro-renewal areas, the main problems of temporary buildings in terms of people's wellbeing are found, which include poor thermal comfort, few spatial functions. Based on this identification of a problem, the study comes up with three major design strategies: modular combination, variable spatial interface and bioclimatic buffering. The modular combination strategy to achieve flexible adaptation of spatial scale, standardization of components and flexible connection methods; the variable spatial interface strategy through movable partition, adjustable facades structure and more, to help restore spatial functions that require time; and the bioclimatic buffering strategy to improve the performance of the built environment through passive design methods, such as double skin structure, shading system and vertical softeners. These strategies rely not only on theoretical analysis, but also on the experience obtained by summarizing cases of advanced domestical and international temporary buildings and thus become practical and innovative.

At the level of strategy implementation, a detailed system of technical parameters was set up. For example, the combination of modular strategy, the basic size of the structural module is 3 m $\times$ 3 m $\times$ 3 m, which satisfies the requirements of transportation and hoisting, and can form a variety of spaces through different combinations. The connection node design adopts the pin-type metal parts to ensure the assembly efficiency and the safety of the structural assembly. In the variable space interface strategy, the study found that the moving speed of the moveable partition should be controlled to 0.1 m/s and noise should be controlled to lower than 45 decibel to guarantee the comfort of users. The bioclimate buffer strategy quantifies some important parameters like shading coefficient (0.3–0.7) of various shading components and improvement value of thermal performance of vertical greening (the surface temperature can be decreased up to 8 °C in summer). These specific technical indicators are guidelines to follow for subsequent design practices [11–12].

B. DESIGN AND IMPLEMENTATION OF PRACTICAL CASES

Based on the above design strategies, this study chose three typical urban micro-renewal cases for the practical principal design, which are temporary activity center designed on the vacant community territory, creative workshop designed in the industrial heritage area, and waterfront service station designed. Each case applied and optimized the design strategies specifically to deal with different spatial characteristics and needs of use. The temporary activity center on a vacant community space on a high-density built-up community space, is about 300 square meter and basically serves the daily activity and social needs of community residents. The design is based on the double-layer modular structure, the shading structure is adjustable on the outside layer and the functional module combination is on the inside layer, and a thermal buffer space exists in between. The building's orientation was optimized, with the major light-receiving surface at a 15-degree angle to the southeast in order to maximize winter sun but not sit in the direct line of center for excessive summer heat. The creative workshops in the industrial heritage area focus on culture and creativity functions and need to meet several purposes such as exhibition and workshops and intercultural. The design maintains the steel frame structure of the old factory building and incorporates the lightweight composite modular units in order to create a unique space combining the old and the new. The layout in space is radial, where a common work area is located centrally and relatively independent working units surround the central space, guaranteeing not only the visual interconnection of spaces but also the existence of certain areas of controlled privacy. To address energy consumption issues in large spaces, a smart skylight system powered by building-integrated photovoltaics (BIPV) technology was designed. The skylight frame integrates a high-efficiency flexible solar film, autonomously powering the skylight's opening and closing motor and built-in environmental sensors. This allows the system to automatically adjust its opening and closing based on indoor and outdoor temperature and humidity, eliminating reliance on an external power grid. Simultaneously, the system employs a low-maintenance design; the skylight surface is covered with a self-cleaning nano-coating to reduce the frequency of manual cleaning, and key drive components utilize weather-resistant, quick-plug modular components for easy maintenance and replacement. This system, in conjunction with a low-speed ceiling fan, promotes air circulation and ensures thermal comfort. The waterfront space service station is a focus on the integration of the natural environment. The building form has a streamlined design that minimizes the waterfront landscape obstruction. The building materials used are bio-based materials such as bamboo and wood which is in line with the concept of eco-friendliness. The bottom of the building adopts a reversible floors to avoid permanent impact on the ecology of the waterfront [13].

During the implementation process, the team of researchers collaborated closely with the construction units, documenting important data at each step, including the transportation of building materials, prefabrication of components and on-site assembly of components. Particular attention was paid to sustainability indicators like consumptions of energy during construction, waste production, and construction period, as a basis for further evaluation. At the same time, BIM technology was applied to full-process management, optimization of construction sequence, on-site modification reduction, and construction efficiency improvement. The actual construction cycles for the three cases were between 45 and 60 days, which is shorter than traditional buildings, thus proving the merits of temporary buildings, which can quickly respond to the needs of urban space.

Table 1 below summarizes the comparison of key design parameters and preliminary sustainability indicators in three case studies:

C. DATA COLLECTION AND EVALUATION METHODS

To scientifically evaluate the effectiveness of the design practices, a multi-dimensional data acquisition system was established, comprising three main methods: physical environment monitoring, space usage observation, and user questionnaire surveys. Physical environment monitoring was conducted continuously throughout the building's use, with monitoring points evenly distributed according to spatial functional zones, and 12-15 monitoring points set up for each case. Monitoring parameters included environmental indicators such as air temperature, relative humidity, PM2.5 concentration, noise level, and illuminance, with data collected every 10 minutes.

Prior to the formal evaluation, the study conducted a 48-day pre-monitoring period on three case studies [14–15]. Figure 1 shows the temporal changes of key parameters of indoor thermal environment (air temperature) and air quality (PM2.5 concentration) collected during this period, reflecting the environmental performance and differences of different case buildings under typical operating conditions:

Preliminary monitoring data shows that the indoor environmental parameters of the three case buildings change regularly over time, and due to differences in design strategies and spatial functions, there are observable differences in their temperature control performance and air quality.

The monitoring equipment undergoes standardized calibration to ensure data accuracy. Additionally, reference monitoring points are set up outside the building to compare differences between indoor and outdoor environments.

Space usage observation was used as a timed recording technique, specifically systematically recording the quantity of users, activity type and dwell time in each space in different time periods (morning, noon and evening) on weekdays and weekends. The observation period was for two consecutive weeks with different weather conditions. Analysis of data on space usage enables to determine the rationality and adaptation of the functionality of the space. The survey method in user questionnaires was random sampling, no less than 100 valid questionnaires were collected from each site of case. The questionnaires contained basic information such as the users age, gender, occupation including subjective information such as the satisfaction with the space environment, the functional suitability and the psychological feelings. The questionnaire was based on a 5-point Likert-scale, and was also supplemented with open-ended questions to obtain specific suggestions. In addition, the study measures and monitors sustainability measures like energy use in buildings and water resource usage. Energy consumption information is logged in real time using smart meters, showing separation of various end-uses with regard to lighting, air conditioning, and sockets. Water resource utilization is calculated by information of water meter, as

TABLE 1. Comparison of Key Design Parameters and Sustainability Indicators in Practical Cases

Case Name	Structural form	Main materials	Basic module dimensions (m)	Construction period (days)	Expected material recycling rate (%)
Temporary activity center on vacant community land	Modular steel structure, adjustable shading system	Light steel structure, composite insulation board, recycled wood	3.0 × 3.0 × 3.0	45	78
Creative workshops in industrial heritage areas	A combination of old and new structures (retaining the original steel frame + incorporating new modules)	Steel, precast concrete cladding, Low-E glass	4.5 × 4.5 × 4.0	60	82
Waterfront Space Service Station	Lightweight wood structure, reversible foundation	Glulam, bamboo, polycarbonate sheets	2.5 × 2.5 × 2.8	50	85

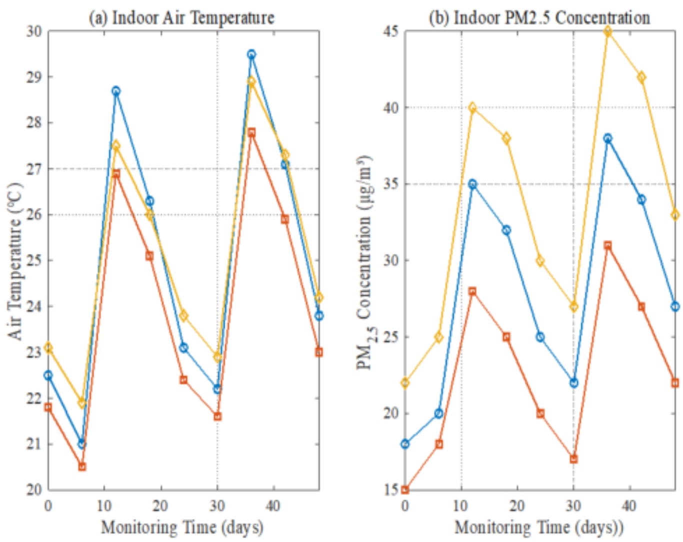

FIGURE 1. Time-series changes of indoor environmental parameters during the pre-monitoring period of the case building

well as observation of water utilization points to calculate water utilization per unit area and water-saving efficiency. All data is entered into an especially designed database and processed using statistical analysis software. The evaluation index system consists of basic indicators such as thermal comfort index, space utilization efficiency, and user satisfaction score. The calculation methods for these indicators all refer to relevant standards and specifications in order to ensure the scientific validity and comparability of the evaluation results.

IV. RESULTS AND DISCUSSION

A. ENVIRONMENTAL PERFORMANCE AND PHYSICAL COMFORT ANALYSIS

Through the continuous monitoring of three case studies the study was able to gain some information on the environmental performance of temporary buildings. Regarding the thermal environment, the temporary buildings whose thermal environment is designed using a bioclimate buffering strategy have excellent temperature regulation capabilities. In July, the hottest month of summer, when the peak outdoor temperature reached 38.2 °C (the monitoring point was located in an open area on the north side of the building to avoid interference from the building's shadow), the average indoor temperature was 3.8 degrees Celsius lower than the outdoor temperature, and the temperature fluctuation was also reduced by 45%. In particular, the doubleskin design enhanced significantly the thermal performance of the building envelope and can keep the indoor temperature in the comfort temperature range (18 to 26 degrees Celsius of temperature) for 82% of the time over the transition season. The vertical greening system not only regulated the microclimate in the building but also ameliorated the quality of air in the building; monitoring showed that PM2.5 concentrations are 15%–20% lower in areas adjacent to the green spaces compared to other parts of the building.

Analysis of the results of natural lighting performance in: through the optimized design of windows and light reflection products, the average indoor daylight factor in the three cases reached 2.8%, which can reach the requirements of green building standards. The average illuminance on the work surface was between 300–500 lux, with a level of uniformity equal to 0.6, avoiding strong glare. Acoustic environment testing results show that under the influence of the temporary building structure with relatively light weight, through the internal sound-absorbing material and the reasonable layout of the space, the indoor background noise was controlled under 45 decibels, and the speech intelligibility was 0.7, which is enough to meet normal communication requirements.

Cross-analysis of environmental monitoring data and user satisfaction surveys for user evaluations showed a significant correlation of physical environmental parameters and subjective comfort evaluations. When the indoor temperature was between 22–26 °C and relative humidity between 40%–60%, user satisfaction to thermal comfort was more than 85%. The correlation between daylight satisfaction and illuminance uniformity (r=0.79) was found to be greater than the correlation of the same with absolute illuminance (r=0.52), suggesting that light quality is more important than its quantity. These findings suggest specific advice on the environmental design of temporary buildings, such that it is the overall balance of environmental performance that is considered, and not to optimise a particular parameter.

B. SPACE FUNCTIONAL USE EFFICIENCY ASSESSMENT

Space usage observations showed the flexible space design had a great contribution to the flexible function of temporary buildings. In the case of the community activity center, a movable partition system is effectively used for supporting the three different functions in one day: senior fitness, children's extra-curricular activities, and community meetings. The space utilization rate (actual usage time/available usage time) was 78%, which is higher than the average of 65% for similar permanent buildings. The radiality of the creative workshops allowed for spontaneous interactions between different creative groups; an average of 8.3 cross-workstation interactions per hour were also recorded during the observation period. This informal exchange was seen as an important impetus for creative production.

The multifunctional design also has some challenges. During maximum hours of the weekend, when the community activity center multi-functional hall is at the same time dining and event center, noise pollution becomes special. Monitoring reveals that noise levels are 8 decibels higher than normal which causes a corresponding reduction in user satisfaction of the acoustic environment. This finding implies the need for more refined functional zoning strategies for future designs in particular the separation of activities that have different acoustic requirements (in terms of time and space).

Space use observations show that the variable space design significantly improves the functional adaptability of temporary buildings. Quantitative observation results for key space use indicators are shown in Table 2.

The user survey results show that the spatial functions of the temporary buildings generally meet the needs of users. 88% of respondents answered affirmatively to the question "Does the spatial layout meet the needs of the activities?", and 85% were satisfied with the "spatial flexibility." Analysis of open-ended questions indicates that users particularly appreciated adjustable furniture and multi-functional area designs, believing these designs allow the space to adapt to the needs of different groups and activity types. Users also suggested adding more private small spaces and improving storage functionality; this feedback provides direction for future design optimization.

C. SUSTAINABLE ENERGY AND ITS CONTRIBUTION TO HUMAN WELL-BEING

From a life-cycle perspective, temporary buildings demonstrate significant resource efficiency advantages. The average building material usage in the three cases was 45.2% of that in traditional buildings, and construction energy consumption was only 30.4%. Modular design allows building components to have high reuse potential after disassembly, with an expected material recycling rate of 85%. Regarding water resource utilization, through rainwater harvesting and the application of water-saving appliances, the daily water consumption of the case buildings was 40% lower than that of similar traditional buildings. In terms of contributions to human well-being, research using psychological scales found that users experienced an average 26% reduction in stress levels and a 32% increase in social connection after using the temporary building spaces. This psychological benefit is partly attributed to the close integration of the building with the natural environment—areas with good visual connectivity to the outdoors in the three cases generally had 15–20 points higher user satisfaction scores. The informal and welcoming nature of temporary buildings also lowers the barrier to entry, promoting integration among different community groups. User statistics from the community activity center show that the space successfully attracted teenagers and the elderly who rarely use community facilities, with these two groups accounting for 45% of weekly visitors.

The discussion section analyses the distinctive value of temporary buildings in an urban micro-renewal. Compared to traditional permanent buildings, temporary buildings have great advantages to encourage social experimentation and functional innovation. Their "temporary" nature makes trial and error much cheaper and allows communities to experiment with new ways of using space. At the same time, the study also identifies the challenges encountered by temporary buildings, including public concerns over the quality of the buildings, and ambiguity in terms of management and maintenance responsibilities. Solving these problems demands multi-party collaboration in terms of design strategies, management mechanisms and social participation.

V. CONCLUSION

This study systematically investigates sustainable temporary building design methods by integrating high-performance lightweight enclosure materials with human well-being through theoretical exploration and design practice. By utilizing the breathability and structural adaptability of advanced fiber materials, the research develops innovative architectural solutions that prioritize environmental health and spatial flexibility. The research shows that through innovative strategies such as modular design, variable spatial interfaces, and bioclimatic buffering, temporary buildings can significantly improve environmental performance and functional adaptability, providing sustainable and resilient solutions for urban micro-renewal. Practical case studies

TABLE 2. Summary of Observation Indicators for Functional Use of Building Space in Case Studies

Observation indicators	Community Activity Center	Creative Workshop	Waterfront Service Station	Phenomena and Challenges
Average daily space utilization rate (%)	78	65	72	Community centers have frequent and diverse needs.
Maximum number of function conversions per day	3	2	2	Movable partition systems enhance flexibility.
Average number of cross-unit interactions (times/hour)	5.1	8.3	4.2	The layout of creative workshops promotes spontaneous exchanges.
Peak-hour noise increase (dB)	8	5	3	Functional combination causes acoustic interference.
Functional requirement satisfaction rate (affirmative percentage in questionnaires)	88	85	90	Overall functional settings match requirements.
Space flexibility satisfaction (%)	85	88	82	Customizable interfaces and furniture gain recognition.

demonstrate that good temporary building design can not only effectively improve physical comfort but also promote social interaction and community integration, generating multi-dimensional positive impacts on human well-being.

The research also disclosed the difficulties in the development of temporary buildings with lack of technical standards, public bias, and even unsound management mechanisms. The future of temporary architecture relies on advanced technical support and management innovation, specifically through the integration of standardized high-performance modular components and reversible lightweight enclosure technologies that enhance adaptability and sustainability throughout the building's full life cycle.

AUTHOR CONTRIBUTIONS

Zhuolin Zhou designed, collected and analyzed the data, and drafted the manuscript. Zhuolin Zhou conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Zhuolin Zhou participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research received no external funding.

ACKNOWLEDGEMENTS

Not applicable.

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